Escola d'Enginyeria de Telecomunicació i Aeroespacial de Castelldefels
UNIVERSITAT POLITÈCNICA DE CATALUNYA

Master's degree in Applications and Technologies for Unmanned Aircraft Systems

MASTER'S THESIS

MASTER'S THESIS TITLE: Analysis of the UAS regulatory frame for mapKITE, a new drone-based concept for geo-data acquisition

TITULATION: Master's degree in Applications and Technologies for Unmanned Aircraft Systems (Drones)

AUTHOR: Marc Rabella Sueiras

DIRECTOR: Pere Molina Mazón

DATE: July 6th 2018

Title: Analysis of the UAS regulatory frame for mapKITE, a new drone-based concept for geo-data acquisition

Author: Marc Rabella Sueiras

Director: Pere Molina Mazón

Date: July 6th 2018

Overview

This document contains, on the one hand, an exhaustive study of the drones' legal framework with a focus on the GeoNumerics' project named mapKITE.
mapKITE is a patented application with some special characteristics in regards to the other drone applications so, for this reason, its insertion into the European and other certain countries' regulations is important.
On the other hand, it also contains the design and implementation process of a Graphical User Interface that will be useful for changing the mapKITE's drone flight parameters in real time and in the most graphical and handy way.
This is an important part because this tool will allow the user to have maximum control over the UAV and thereby staying within the given regulatory parameters, although some of these drone regulations can be quite strict sometimes.

Acknowledgement

I would like to express my thanks to the nearer people around me. All of them have encouraged me to move forward with the project and have asked continually for its state of evolution. This has been my drive in order to finish it on time.

I would like to give a great thank you to my Pachawa Sound colleagues for balancing the team workload and featuring a combined very precise schedule with enough space for all of us to continue maintaining a ‘double life’.

Then, I have to give a very special thank you to Marc Bosch as my thesis’ English reviewer. He has invested his language knowledge into this document during his degree’s exams week, and for me this has a lot of value.

To finish, many thanks to my company colleagues Àlvar, David, Abraham, the Martas, Ismael and Pere for giving me their support at any time I needed and in Pere’s case for a thesis tracking, without pressure, and ‘made to measure’.

Thanks to Juan López for making the work easier with their tools in many different fields. A big thank you to all the Master’s teachers for their great knowledge and flexibility, taking into account that this is the 1st year of the Master’s degree and of course, for putting a little part of humour into many aspects, I want to give a special thank you to Miguel Valero.

ÍNDEX

INTRODUCTION

Nowadays there are lots of drone applications around the world. Many of them are related with acquiring geographical data to do terrain studies in a new, more efficient way. This is GeoNumerics' field.

Drones have entered strong into this sector performing all type of 'geo' applications, a sector which was distributed between surveyors, some companies using Terrestrial Mobile Mapping Systems (TMM) and other ones using aerial imagery caught by manned aircraft.

The principal geomatics project of GeoNumerics is named mapKITE. Its main advantage is the combination of both TMM and drone data. Linked as a tandem, a Terrestrial Vehicle (TV) and an Unmanned Aircraft Vehicle (UAV), perform corridor mapping in different types of terrain such as roadways, railways or waterways, including coasts and cliffs.

Although there are two types of mobile systems, if a project includes a drone can be considered as a drone application, and every drone project can be divided into four parts, the resulting ones would be: the Unmanned Aircraft (UA), the payload, the system integration and the regulatory framework.

In mapKITE's case, the UA and the payload selection are the client's responsibility, and also depend on its intended application. Although it would make sense to study which combinations would be best fitted to a certain type of terrain and application, these points shall not be evaluated in this thesis, as its main focus is centred around the previously explained last two last blocks, because they are the ones less consolidated along mapKITE's development.

CHAPTER 1. OBJECTIVES, REFERENCES & MOTIVATIONS

1.1. References & motivations

The basic motivation of this thesis is to help GeoNumerics complementing its original project with the further development of the parts in which they have less knowledge. The facts that is a drone project, innovative and patented are a plus that is also a motivation.
Another reason for putting my efforts in mapKITE's development is in order to use my recently acquired capacities in a drone project because, in my opinion, this is the best way to internalize any type of knowledge.

In regards to the references, it is important to say that I did not know about almost any drone company or other type of companies who have drone projects. Taking a look at the master's companies' catalogue, one of the bests project description was GeoNumerics' one, and when I saw their website, it was clear that they had a very good working method, although they were not a completely drone focused company. This reference, in combination with a talk with the master's coordinators about the company, became to a really big motivation for this project.

1.2. Objectives of the thesis

The main objectives of this thesis are to develop a regulations study focused on mapKITE and to contribute to its Ground Control Station (GCS).

The regulations study is a really important part for every drone project, because nowadays the UA regulatory framework is changing a lot in all countries due to the market's continuous growth.
In mapKITE's case it is more important because of its special conditions or characteristics like the 'follow-me' capability.

The GCS complementation is not critical but is very desirable because it consists of a Graphical User Interface (GUI) development. The aim of it is to allow for an easier change in the mission parameters, and as mapKITE missions are a bit special it would not be enough to change conventional drone parameters, but also there are some additional required ones, which are explained in section 4.2.

CHAPTER 2. mapKITE DESCRIPTION

2.1. Objective of the project

mapKITE is a new type of mapping concept in a well-defined niche market (geoinformation in general, mapping more specifically, photogrammetry and remote sensing even more specifically) with companies (end-users of the technology) and companies/institutions (end-users of the geoinformation generated by the technology) prepared to operate and use the technology and results, respectively.

The project embodies many innovative ideas grouped under two new paradigms: (1) the new tandem terrestrial-aerial geodata acquisition and (2) the use of the terrestrial vehicle to provide continuous ground control point information together with a new type of photogrammetric pointing-and-scaling measurements.

Geoinformation is a fundamental infrastructure of modern society as many other infrastructures and services depend on it (just to name a few, Location Based Services (LBS), smart cities, security and law enforcement, disaster management, land and cadastral management, energy management or climate change monitoring). Yet, geoinformation (the modern 3D maps and beyond) is expensive to create as well as to update. European, national and local governmental agencies in charge of geoinformation have to cope with a growing professional and popular demand for high-resolution, up-to-date geoinformation facing decreasing budgets. mapKITE eliminates the need for separate surveys (terrestrial separated from aerial) and uses low cost gears (small unmanned aircraft as opposed to manned aircraft), presenting thus a much less expensive option, delivering comparable or even better results. Its environmental impact (acoustic and pollutive) is also less than traditional systems, as mapKITE is based on small UAs with electrical rotors, compared to the bigger aircraft engines used in other methods [1].

2.2. General Scheme

mapKITE is built upon combining an aerial and a terrestrial component. The aerial component consists of a UAV equipped with remote sensing payload and a navigation, guidance and control system (i.e autopilot), and a TV, driven by a human operator and equipped with remote sensing instruments and a real-time navigation system. This tandem operates in the following way: the TV computes

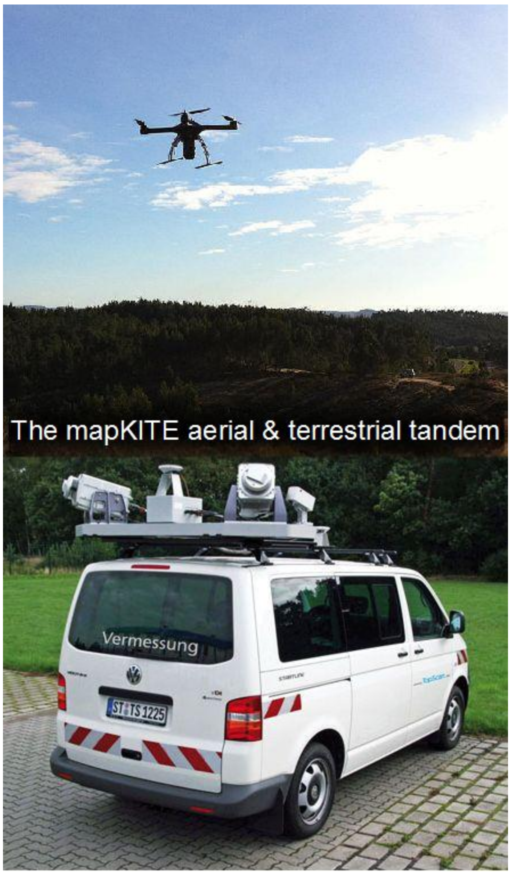

Fig. 2.1 mapKITE tandem

a real-time trajectory by means of its real-time (high-grade) navigation system. By doing so, a set of waypoints are generated as route inputs for the UAV just by converting TV navigation (time, position, velocity and attitude parameters) into UA commands (height and heading to be followed at each epoch). Such a mechanism creates a 'virtual tether' by which the UA always follows the TV.

In order to provide the necessary robustness level to the virtual tether, two key features are added in mapKITE. Firstly, the use of the new Galileo E5 AltBOC modulation with unique properties against GNSS multipath will ensure error mitigation in the computation of the TV navigation solution. And secondly, a target-tracking system will be available in the UA to identify and track in real-time a target (placed on the TV and visible from the UA) and therefore to perform precise relative TV-UA navigation [1].

2.3. Type of operations

As any type of vehicle can more or less carry a Mobile Mapping System (MMS), as depicted in Figure 2.1, and the virtual tether is not limited to any type of TV, mapKITE has a big range of flexibility in the type of operations that it can perform.

On the other hand, mapKITE's characteristics show that it cannot be the optimal solution for all types of operations. As a tandem cycle is not optimal for covering a vast area, mapKITE neither, but probably it is still the best choice to perform corridor mapping. The word 'corridor' implies narrow straight or curved paths, so roadways, railways and waterways are included; and with different TV, cliffs and coasts can also be included. In Figure 2.2 all of these are well represented.

Fig. 2.2 mapKITE operations' possibilities

2.4. Legal challenges

The principal legal challenge for mapKITE is the fact that one has to drive the drone from a car or any other moving vehicle. This measure is as innovative as it sounds, but it also means that almost no country regulation framework takes it into account, making it a key point when facing the legal aspects of mapKITE usage. It is a critical requirement for the project to succeed.

A second legal challenge is to be allowed to fly over other vehicles or infrastructures, a very restricted measure until now. Corridor mapping implies flying the drone over roads and railways and, if we take into account ‘city/town mapping’, buildings and other urban structures have to be included as necessary overflown infrastructures. As mentioned before the regulations are evolving continuously and some countries have put some conditions to perform these type of flights that entail a really sophisticated hardware and planning, but there is still the possibility of doing it.

The third legal challenge is the possibility of driving the UAV manually by a certified drone pilot from within the moving vehicle. This is neither conventional but it can be a way to maintain the VLOS restriction, and get the control of the drone if the communication with the GCS is lost.

Then the other requirements are less important, flying over people to have the possibility to perform operations without cordoning off the place for example.

These three mapKITE-regulations challenges are so important that, apart from describing the UAV legal frameworks of some important countries in the following paragraph, we have consulted a drone legal expert in order to know his opinion on the way these challenges could be faced, and therefore being able to operate mapKITE everywhere. This drone legal expert is named Filippo Tomassello and his opinion is exposed in Annex III.

CHAPTER 3. REGULATIONS

This chapter presents the current (3.1) and the future regulations (3.2) of mapKITE's principal targeted countries.

The countries have been chosen for different reasons:

- Europe is not a country but a group of them and it has been chosen because of its latent development of a united European drone regulation framework that will suppose a big 'push' in the drone legal paradigm all around the world. The other reason for choosing it is because GeoNumerics is a Europe-based company.
- Spain has been chosen for the same reason as Europe, as GeoNumerics is a Spain-based company and because of the mapKITE's Spanish patent holding.
- France has been chosen because at the time this master's thesis is being realized, GeoNumerics has an active project of mapKITE implementation in France[1]. An experience summary of this mission can be found in Annex II.
- Brazil has been chosen due to the traditional cooperation of GeoNumerics with ENGEMAP, a Brazilian partner, and also because there is an active patent process of mapKITE there.
- The 'other countries' paragraph is useful for comparing the direct target countries' regulations with other important ones. The United Kingdom has been chosen as it is a European country, but out of scope of the European Union laws. The United States have also been selected, as the most advanced country in the world, technology-wise, and because of their unique comprehension of aeronautics.

3.1. Current regulation

3.1.1. European Union

Nowadays there is not a specific regulation framework for typical drones in Europe because the power to regulate drones resides in each country. The word 'typical' refers to the drones that we are used to see (either for commercial or for particular purposes).

For the time being, Europe and its aeronautical management organization EASA, has the task of providing some limits and advices to the European countries that could help in their drone legal structure development. Nevertheless, what it has been developed by EASA and it is applicable in the whole Europe is a regulation

[1] HYCOS project explanation can be found at: http://www.geonumerics.es/index.php/news/70-kick-off-of-the-hycos-project-co-coordinated-by-geonumerics-an-application-of-mapkite-to-coastal-monitoring

framework, only applicable to unmanned aircraft with an MTOM above 150 kg that are not used for military, customs, police, firefighting, search and rescue, or experimental work.
This type of drone is not applicable to a mapKITE mission, and so this part of the regulation will not be exposed here.

On another front, EASA in collaboration with JARUS and many drone experts from different European countries, are developing a system to regulate the rest of European drones, the ones that are now regulated country by country. The initial part of this ‘drone ecosystem’ development is explained in Annex I.

3.1.2. Spain

BOE #316 29/12/2017

This document substitutes the old drone regulation named 18/2014 and modifies a complementary decree about the air law in Remote Piloted Aircraft Systems (RPAS).
Its application covers all RPAS with MTOM under 150 kg from any sector and some above 150 kg excluded in the European Regulation.

First of all, all drone remote pilots and the observers for the Extended Visual Line Of Sight (EVLOS) mode have to have the drone pilot license, it is mandatory.

All drones have to carry an identification plate with the name and contact mobile number of the company that owns the drone, then, the drones with an MTOM over 25 kg have to be registered and an airworthiness certificate of them has to be obtained. The organism which controls the license expedition and the registration is AESA (‘Agencia Estatal de Seguridad Aérea’).

For aircraft without the airworthiness certificate the restrictions are the following: the operation has to be performed under the visual scope of the pilot, Visual Line Of Sight (VLOS) or under the visual scope of observers in permanent radio contact with the pilot, EVLOS. The horizontal distance from the pilot or the observers cannot exceed 500 m, the vertical height above the terrain or the highest obstacle in a radius of 150 m (500 ft) from the aircraft cannot exceed 120 m (400 ft).

Moreover, to perform Beyond Visual Line Of Sight (BVLOS) specialised operations:

- If the aircraft has an MTOM over 2 kg and does not have any Detect and Avoid (DA) system, the operation should be taken in a Temporary Segregated Airspace (TSA).

- Otherwise this type of operations should be taken in a non-controlled airspace or in a Flight Information Zone (FIZ) always away from crowded areas or habited places like towns and cities.

To perform specialised operations over crowded areas or inside towns or cities out of FIZ, the following requirements must be met: it has to be in non-controlled airspace, the aircraft's MTOM cannot exceed 10 kg, the operation has to be taken in VLOS, the maximum horizontal distance is 100 m and the maximum height above the terrain or the highest obstacle in a radius of 600 m from the aircraft is 120 m (400 ft). Furthermore, these flights should be performed over a bounded perimeter that limits the people or vehicle traffic. And so the minimum horizontal distance from buildings or other type of structures and non-participating people has to be of at least 50 m.

Aircraft with their airworthiness certificate could operate under the restrictions posed in that document. Nevertheless, if they do not have a DA system they could not operate in BVLOS if there is no TSA for that effect.

The minimum distance from airports can be accorded with the place manager and the same happens with other infrastructures or facilities where the flight over them should be accorded with the people responsible for them.

All flights, without exception, have to be performed in Visual Meteorological Conditions (VMC), which are defined in the article 23 ter.2 of the royal decree 552/2014. As a summary it can be said that complying with the regulated VMC should allow the drone pilot to see the drone almost until the regulatory limits without problems.

To perform night flights it is necessary to have an authorization explicitly from AESA.

All drone operators must have all of the RPAS' documentation, its insurance policy and the operations manual.

When focusing on the 'follow-me' application, it is allowed to drive the UAV from a moving terrestrial vehicle if an operation planning is done and approved by AESA, and there are guarantees that no obstacle will get in the way between the pilot and the drone during the flight, making him lose view of said drone. Another condition to perform this type of operations is to drive the TV at a speed that allows having the awareness of the drone's position at all times. Finally, this cannot be performed using more than one single drone at the same time.

Related to the take-off and landing it is mandatory to establish a 10 m radius security area without people in it when performing these flight phases if the drone can perform a Vertical Take-off and Landing (VTOL). If the chosen aircraft is a fixed wing and so a VTOL is not possible the radius has to be of 30 m. Apart from that the operator has to locate security zones all along the flight for a failure case having the possibility to perform an emergency landing without causing any damage to furniture or people [2].

3.1.3. France

JORF #0298 24/12/2015

This document is complementary to the French transports code: the article L.6211-3 and is not applicable to the balloons, kites or military transportation.

Any flight has to be performed at a maximum height of 150 m over the surface or 50 m above an artificial obstacle that measures more than 100 m. All flights have to be done in non-controlled airspace. Figure 3.1 represents the height limits in each geographical part.

It is forbidden to fly in public spaces such as towns or cities or over crowded areas except in places where the territorial jurisdiction authorizes the practice of said activity.

Flying inside a dangerous or a private restricted area can be accorded with the manager of that area and must be reported to the Flight Information Services (FIS). The same applies to airports or aerodromes, to fly near that facilities it is necessary to have the agreement of the organization and it is mandatory to inform the Air Traffic Services (ATS) [3].

Immersion Flights (FPV) are possible under certain conditions, requiring the presence of a second person to ensure safety. For the same safety reasons, but applied to aircraft flying at low altitude such as helicopters performing rescue operations, regulations prohibit the use of drones at night, even if they are equipped with lighting devices.

Any foreigner that wants to fly a drone in France for recreation purposes or as a professional has to check beforehand if its insurance covers its practice in France.

There are not any ‘follow-me’ or take-off and landing specifications. But for specific operations one should check in with French aeronautical authorities accord the conditions in which to perform them.

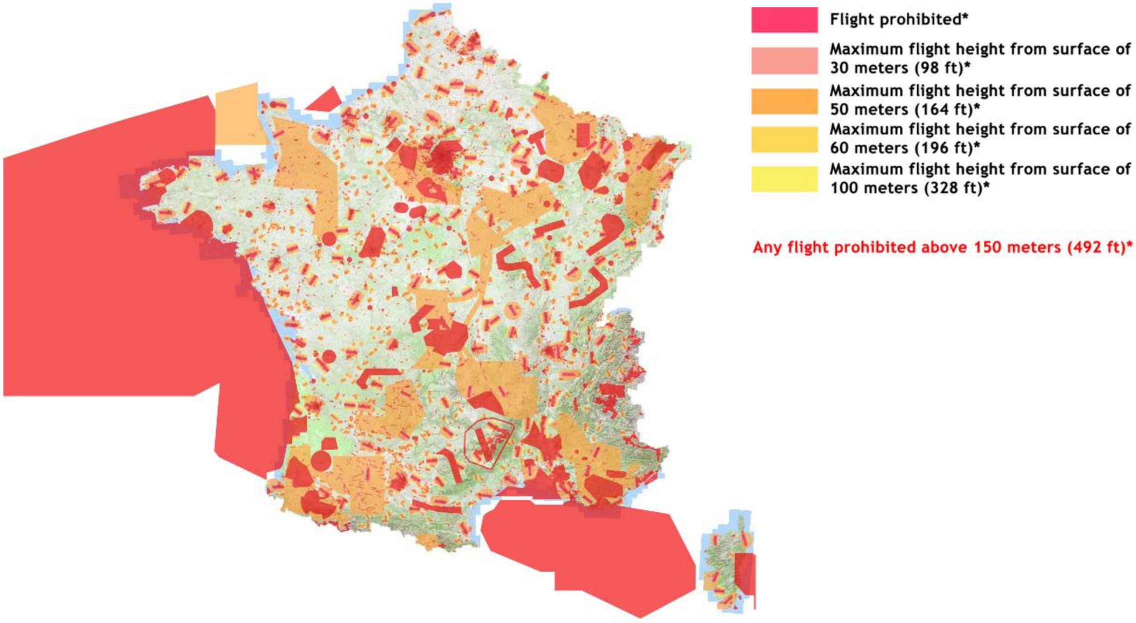

Fig. 3.1 French altitude-limit map

3.1.4. Brazil

RVAC-E No.94

UAV operations in Brazil must follow the new ANAC regulations as well as the regulations established by the Brazilian Air Space Control Department (DECEA) and the National Telecommunications Agency (ANATEL).

First of all, pilots of UAVs under 250 g do not need to have a license to operate flights under 120 m (400 ft). In the remaining cases, to perform operations for commercial purposes a drone pilot license is mandatory.

ANAC divided the UAVs into three categories:

- CATEGORY 1 – UAVs over 150 kg – the equipment must undergo a certification process like the ones required for manned aircraft and must be registered at the Brazilian Aeronautic Registry.
- CATEGORY 2 – UAVs from 25 to 150 kg – technical requirements must be verified by the UAV manufacturer and the equipment must be registered at the Brazilian Aeronautic Registry.
- CATEGORY 3 – UAVs under 25 kg – ANAC regulation determines that UAVs under 25 kg that operate BVLOS or an altitude above 120 m (400 ft) must be registered at ANAC and be part of a project authorized by the agency. UAVs that operate below 120 m (400 ft) and within VLOS do not

need to be part of an authorized project, but need to be registered at ANAC. UAVs under 250 g do not need to be registered.

Apart from that the regulation framework contains other limitations or rules:

- It is forbidden to fly over people or large crowds and/or flying within 30 m of anyone who is not associated with the operation. In urban areas the flight must be performed under 60 m (200 ft).
- It is not allowed to fly over airports or in areas where manned aircraft are operating.
- The flight must be done during daylight hours and only in good weather conditions.
- All drone pilots must be at least 18 years old, and FPV is not allowed taking into account that the drone has to be kept within visual sight at all times.

There are no specifications on ‘follow-me’ applications or take-off and landing restrictions [4].

3.1.5. Other countries

UNITED KINGDOM

The basic rules for foreign operators rely on the basis that they should be able to satisfy the same basic safety requirements that are required for UK based operators.
This will depend on the evidence of ‘pilot competency’ that the applicant is able to provide and the location(s) where the flight is going to take place.

The regulation remarks that a person must not recklessly or negligently cause or permit an aircraft to endanger any person or property.

Drones under 20 kg must be flown no higher than 120 m and kept at least 50 m away from people and private property, and 150 m from crowds and built up areas.
The drone must be kept in line of sight at all times, and No Fly Zones (NFZ) must be avoided.

The majority of NFZ are located over airports and prisons.

Drones over 7 kg must not be flown:

- In Class A, C, D or E airspaces unless the permission of the appropriate air traffic control unit has been obtained.

- Within an aerodrome traffic zone during the notified hours of watch of the air traffic control unit (if any) at that aerodrome, unless the permission of any such air traffic control unit has been obtained.
- At a height over 120 m (400 ft) above the surface.

Commercial operations cannot be performed without the permission of CAA. This permission must take into account all ‘special’ operations or specific cases as well as needed insurance policies [5].

UNITED STATES

To fly a drone for commercial purposes in America the pilot has to be at least 16 years old and must hold a remote pilot airman certificate with a small UAS rating or have the direct supervision of someone who does.

The air limitations are flying under 120 m (400 ft) above ground level or if above this altitude remain 120 m (400 ft) away from structures.

The drone must be kept in eyesight at all times or having a spotter to fly BVLOS.

As a special characteristic, the United States have a speed limitation of 100 mph (160 km/h). Moreover, drones have to yield right of way to manned aircraft.

It is forbidden to fly over people or from a moving vehicle, unless in a rural area. There are specific areas and airspace classifications where the aircraft can fly pending Air Traffic Control permission, while others do not require such permission.

Launching, landing or operating unmanned aerial aircraft is prohibited on lands and waters administrated by the National Parks service in these areas. Figure 3.2 represents a part of the American ‘no-fly zones’.

It is forbidden too to fly near an airport, a heliport, power lines, a stadium, a fireworks show or a fire.

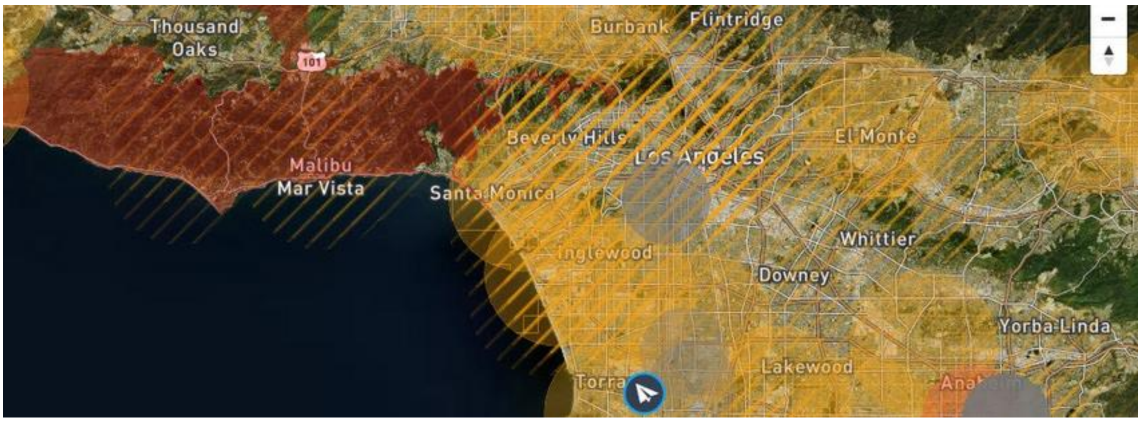

Fig. 3.2 United States drone no-fly zones map

The time limitations are between 30 minutes before official sunrise to 30 minutes after official sunset, with appropriate anti-collision lightning onboard.

The drone must pass the Transportation Security Administration vetting and must be registered if weights over 25 kg [6].

3.2. Future regulation

3.2.1. European Union

There is a European regulation framework planned to be implemented in its totality in 2020, that is currently still under development. This has been planned similarly to other aeronautical definitions in Europe: taking into account the opinion of the sector experts, and a four-month consultation period is being carried out nowadays.

The current proposal distinguishes three categories of drone operations:

- Open: it is a category of UAS operations that, considering the risks involved, does not require a prior authorisation by the competent authority nor a declaration by the UAS operator before the operation takes place.
- Specific: it is a category of UAS operations that, considering the risks involved, requires an authorisation by the competent authority before the operation takes place, taking into account the mitigation measures identified in an operational risk assessment, except for certain standard scenarios where a declaration by the operator is sufficient or when the operator holds a light UAS operator certificate (LUC) with the appropriate privileges.
- Certified: is a category of UA operations that, considering the risks involved, requires the certification of the UAS, a licensed remote pilot and an operator approved by the competent authority, in order to ensure an appropriate safety level [7].

For more information about the construction of Blue Space consult Annex I.

3.2.2. Target countries

There is no future drone regulation planned for Spain. In 2020 the European drone regulatory framework will be completely applied and the countries' drone law modifications or updating should be done before 2018, for this reason Spain hurried up for applying their new rules until that date.

France has no future drone law updating planned for two reasons: the first one is because they are not in-time to change the drone regulatory framework as in 2020 the European regulation will be fully applied, and they have not done any changes until 2018. The second reason explains why: the French first drone regulation was much more permissive, compared to the Spanish one as an example, and any case could be accorded with French authorizations to perform the operation; or to change some little operation parameters in accordance to the authorities, and be able to make an exception out of it and be allowed to perform the mission.

The last release of drone regulations in Brazil is dated in May 2017 so for the moment there is no future drone regulation planned for this country.

3.2.3. Other countries

UNITED KINGDOM

The drone regulations in the United Kingdom have been updated recently in 2017 as well as Spanish ones in order to clarify some specific cases until the European drone regulatory framework is applied, so there is not a future regulation planned.

UNITED STATES

The United States have been updated their UAS regulations in 2018 and therefore no future regulation is planned at the moment.

CHAPTER 4. mapKITE's SIMULATION DESCRIPTION

4.1. The simulation environment

As said in the introduction paragraph, the used GCS for mapKITE is Mission Planner as it is one of the most popular around the world, and for this reason almost all drone pilots or companies have it in their computers and know how to use it. Moreover, it is an open-source software so it is allowed to add modifications that complement the tool. Finally, it includes a basic 'follow-me' functionality, which has served as a basis for the GCS guidance mechanism in mapKITE.

Other GCS are described and compared in table 4.1 [8] [9]:

Table 4.1 GCS Comparison

GCS	Platform					License		Follow-me functionality
						Open-source	Proprietary	
Mission Planner								
APM Planner 2.0								
QGround Control								
Universal GCS						UgCS open		
Tower (DroidPlanner 3)								
MAV Pilot 1.4								
SidePilot								
AndroPilot								

The key point of any drone mission is the possibility to simulate it before its real performance application, and Mission Planner has a really useful tool to do it. Its name is Software In The Loop (SITL) and the way to build a simulation is described in Mission Planner's website[2].

[2] SITL described steps can be found at: http://ardupilot.org/dev/docs/sitl-simulator-software-in-the-loop.html

Another point that makes Mission Planner among the most popular GCS is that it uses MAVlink as the communications open protocol, the one used in almost all drone communications. The 'MAVlink' acronym stands for Micro Air Vehicle Link, and it is designed as a header-only message marshalling library. It was the first specific protocol for UAVs released in 2009 [10].

4.2. Components in the simulation

To simulate a drone mission, having a GCS is not enough. Both a drone simulator and, in the case of mapKITE, a TV simulator are necessary, and the three aforementioned blocks must communicate between themselves in the same PC or in various ones. Figure 4.1 describes the interactions of all these components.

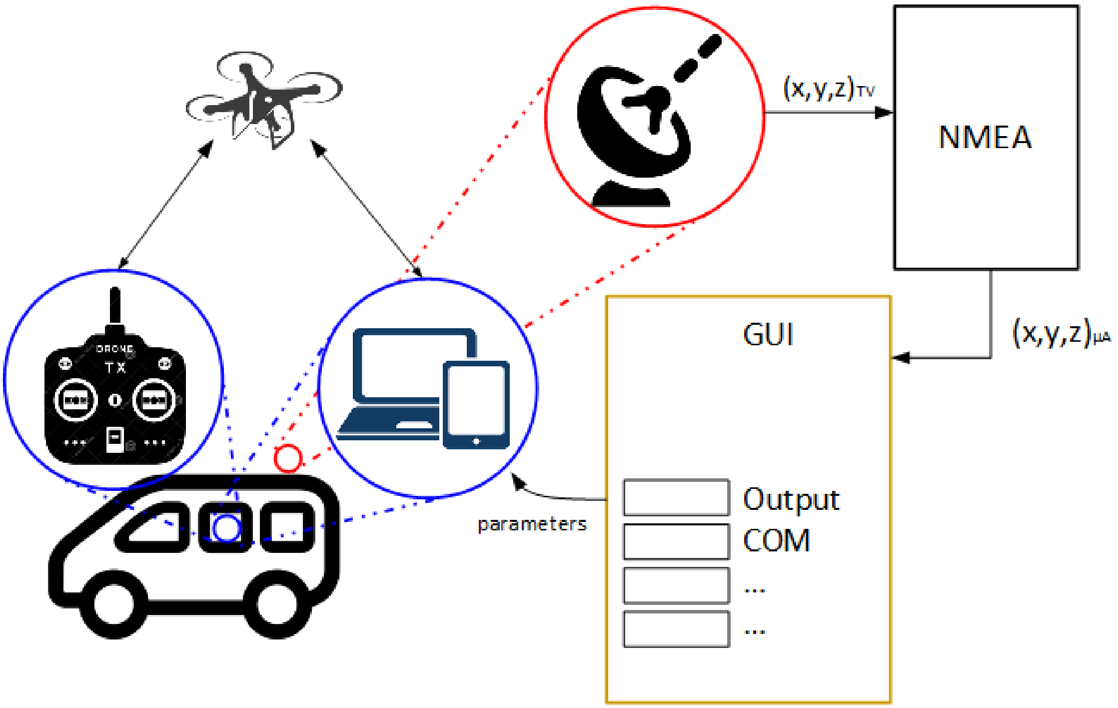

Fig. 4.1 mapKITE general scheme

The UAV simulator that adapts perfectly to Mission Planner and its MAVlink protocol is a software designed specifically for that: MAVproxy[3]. This tool allows the user to simulate not only the drone, but all its basic components (accelerometer and gyroscope) as well as its telemetry parameters. To develop it the designers have taken into account lots of 'log' telemetry files of real drone missions, so the result is a really accurate drone telemetry data evolution.

[3] More information about MAVproxy can be found at: http://ardupilot.github.io/MAVProxy/html/index.html

This means that the flying mode can be changed (altitude hold, guided mode, mission mode…), the simulator presents the arming state of the UA (armed or disarmed), a lot of simulated drone data is 'received': battery percentage, battery voltage, state of the navigation components, heading, roll and pitch angles, altitude, airspeed, throttle percentage… This allows the user to simulate a really precise drone mission. Moreover, MAVproxy allows users to choose between different type of drones, from a fixed-wing to a quadcopter, even up to an octocopter, and the default parameters change between them, having the possibility to change their values to adapt the drone to the mission perfectly.

The TV simulator is very simple compared to MAVproxy. It has been developed by GeoNumerics 'made to measure' because it is a critical piece for mapKITE. It functions as a converter and launcher of position coordinates. As the real TV does, the simulator 'catches the coordinates from the GPS' (catches coordinates from a file), converts them into NMEA format and sends each one through a virtual COM port.

There is a fourth block that we have decided to introduce into Mission Planner's code as a programming function, named Virtual Tether (vTether). This is a specific tool developed by GeoNumerics and included into Mission Planner as an additional feature. It is the core of any mapKITE mission. This is so because it serves to virtually tie the UAV with the TV as its name indicates, and synchronizes one with the other. It has a conversion functionality too that catches the NMEA position coordinates, which is the input 'language' that the software understands, and transforms them into waypoints (WP), which is the input spatial coordinates language of any drone. Apart from that, the vTether tool introduces the capability that allows the user to change some mission parameters that could be nice to adjust during the mission.

Technically talking, vTether has been included in the code solution of Mission Planner as a C# class, so a new Mission Planner has been recompiled and built including it.

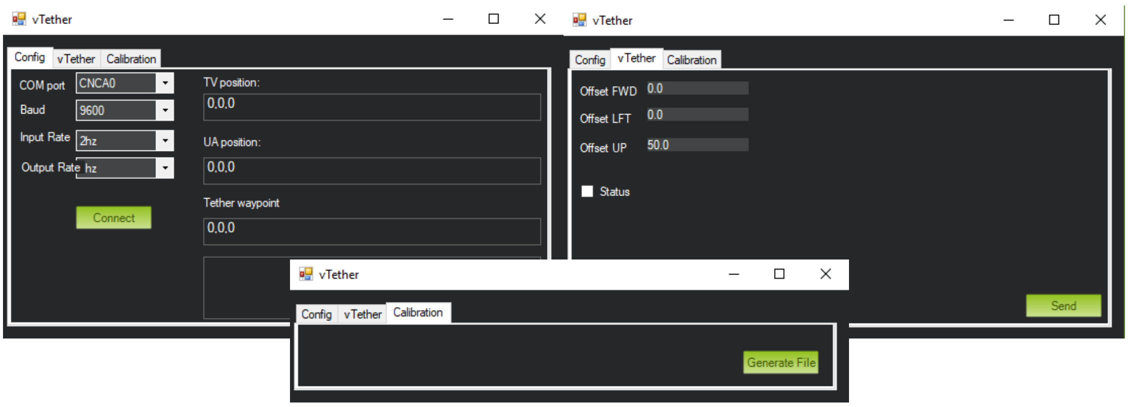

Fig. 4.2 vTether options screens

In figure 4.2 the three different flanges that vTether contains can be seen. In the Config one the COM port, the baud rate and the input and output frequency can be adjusted. The frequencies are related with the waypoint sending, the input frequency refers to the speed at which the coordinates are received from the GPS antenna and the output frequency refers to the speed at which the waypoints are sent to the drone. Moreover, the three types of position information are displayed. The TV position, the UA position and the actual computed waypoint.

The advantage of monitoring these three different stages is checking the internal consistency of the data involved in the waypoint generation.

In the vTether flange the position of the UAV respect to the TV can be configured. Three offsets are enough to determine the exact position: FWD (forward) offset, LFT (left) offset and UP offset. The real nature of this functionality is to modify the point of view of the mission. For example, if at a particular time a corridor requires its left side to be observed (if some area of interest is there), or a higher resolution is required, the vector is modified on-the-fly and new waypoints are automatically modified accordingly. Besides this, there is also the regulations aspect, typically if other vehicles and infrastructures as roads can be overflown and it is not necessary to have visual contact at all time with the drone (described by the countries regulations in Chapter 3) the only used offset will be the UP one in order to keep the size of the optical target paced during the mission path or over the TV at the taken photographs. Then if a visual contact is mandatory, the forward offset will be used and if no roads or other vehicles can be overflown, the left one will be used too. This tab also includes a status checkbox, that indicates if the vTether is active or if it has been disabled and therefore a complementary action needs to be taken.

The third flange is named Calibration and its function is this one exactly. The aim of the 'Generate File' button is to catch the initial latitude/longitude coordinates of the drone and generate a file of waypoints around the initial one, doing a spiral while the drone is ascending, until reaching the final height value in order to calibrate the gimbal properly. Taking some photos of the fiducial target usually placed on the TV from different angles can be crucial to optimize the resolution of the images taken during the mission.

4.3. Steps to simulate a mapKITE mission

Now, to be able to simulate a mapKITE mission is important to take into account the step order, in order to establish all the needed connections before the beginning.

1. Execute Mission Planner: Opening the GCS software is always the first step in a drone mission.
2. Execute MAVproxy: 'Preparing' the UAV should be the second general step in any drone mission and the equivalent in simulation is to open MAVproxy's software.
3. Connect the drone to the GCS: Establishing this link is crucial to communicate with the drone through the PC. It can be done by clicking the 'connect' button in the upper right part of Mission Planner's screen. There is the possibility to change the communications transport protocol and the baud-rate but the default parameters (**UDP** and **115200**) are right in almost any drone mission. Then there is also the possibility to select the local port for the information exchange but again the default one (**14550**) should be the right one.
4. Select a navigation mode: Always the first task to do in a GCS before selecting any other parameter. In this case **guided mode** has to be typed in MAVproxy's console or selected in the 'actions' tab in Mission Planner. This is due to the nature of the guidance in mapKITE, that is a dynamically-changing route (and therefore, not pre-planned).
5. Select the rest of drone parameters: This is the moment to check that all components are on, to program some performance limits in operation as maximum pitch or bank angles or maximum throttle… In this case MAVproxy's default parameters are enough to simulate the mission so nothing has to be changed.
6. Arm the drone: A crucial step before taking off, that switches all engines into flight mode; and as the good GCS and drone simulator that Mission Planner and MAVproxy are, they always require the engines to be in flight mode before the take-off. To do that, '**arm throttle**' has to be typed into the console or marked in the same 'actions' tab as before in the GCS.
7. Take-off: This can be considered a step of the in-mission phase but in this case, we considered it a pre-mission step because the TV is not set up yet. It is always necessary to specify the final height (relative to the take-off point) that the drone will have to reach at the end of this step. Simple as typing for example '**takeoff 50**' into MAVproxy's console or by clicking the right-button on the mouse in the Mission Planner's represented drone silhouette and selecting the take-off option.
8. Execute the TV software: By double-clicking, at that moment a list of coordinates will be launched one by one through COM port 4 (usually linked virtually with COM port 5) that will represent the advancing of the TV through the mission path.
9. Connect the TV to the GCS: Since Mission Planner works as a switchboard, all the information and communications should travel through it. By executing Ctrl+F in the keyboard and clicking on 'Follow-me' option the vTether configuration screen will appear and then COM port 5 has to

be selected and the 'connect' button has to be clicked to establish the TV-UAV connection.

Now the mission path will be tracked in 'real-time' and in Mission Planner's screen (if active) the photos taken and the image overlap during all the mission can be seen.

Note that steps 7, 8 and 9 are slightly different when the calibration procedure is activated (third tab in vTether). In this case, take-off and ascent up to the nominal mission's height are done in Auto mode, following a waypoint set derived from the actual TV position. Unfortunately, vTether calibration functionality is not available yet.

4.4. Additional features in the vTether

The current vTether version is a prototype, designed to cover the 'follow-me' action and provide useful debug information. To be a final closed version would need more usability-oriented functionalities.

Within the main additional features in a future vTether software, the following are considered:

- Include a pin-point symbol in the map view of Mission Planner representing the TV (currently, the pin-point marked as 'guided' just represents the computed waypoint to be followed, and in the mapKITE case, this information is useless and can actually mislead the operator).
- Improve the text boxes in the Config tab.
- Increase the visibility of the Status checkbox in the vTether tab (probably it will be moved to the main Config tab).
- Implement the Calibration procedure in the Calibration tab (currently not active).

CHAPTER 5. RESULTS

5.1. Technical goals of the simulations

The simulations on which this second part of the thesis is based will be (seeing it from the client's point of view) a useful tool to get approximate general data on the drone's performance during the mission. This data can be useful to adjust some features in order to avoid big technical issues during the mission execution; to see graphically that the mission design complies with all the regulations and to get an idea of the duration of the mission.

Indeed, the usefulness of the simulations rely heavily on the ability of a user to model the actual drone to be used in mapKITE as a component of the SITL environment (PID tuning, battery, imaging sensor characteristics, etc.) as well as the terrestrial steering vehicle. If these conditions do not hold, then simulations have to be understood as a qualitative (rather than quantitative) tool.

To go deeper in on how the simulations can help the client, we have focused on two interesting scenarios for mapKITE, based on real projects from GeoNumerics.

5.1.1. Brazilian road cartography

On the one hand we have the Brazilian road cartography, developed with and for ENGEMAP, a Brazilian geospatial company which is a strong partner of GeoNumerics.

Engemap Group has been in the Brazilian market for over 25 years performing geospatial projects for large public and private clients on the national scene.
Since 2014 when the drone paradigm caught power, they planned to begin applying this new technology in their projects in order to satisfy the clients' demands.

Engemap is working focusing in services for highways and railways. They identify great opportunities with the use of mapKITE for mapping these highways and railways to monitor signaling, pavement and train tracks conservation.
In short, they want to apply the same technology for waterways.

They decide to choose mapKITE for several reasons. Firstly, using only Land Mobile Mapping could be not enough to collect all relevant data for the analysis of the customer. Another evaluated method was aerial photogrammetry caught by manned aviation, but it is really expensive due its high operational costs. Finally, satellite images do not have a good enough resolution for this application, so after making some tests they decided that mapKITE was the best solution [11].

5.1.1.1. Applicable regulations' study

In regards to the Brazilian road cartography done in 2014, the drone regulation framework was really different of the one presented in the 3.1.4 paragraph. After the initial growth of the drone market around 2013-2014, the Brazilian government decided to ban any type of drone flights in general cases, so in this particular case, Engemap jointly with Ismael Colomina (the head of GeoNumerics) had to talk and convince not only the Brazilian government, but the authorities and the companies who were interested in mapKITE's final product in order to obtain the permission to perform the mission.
By this way, although the Brazilian drone law was really contradictory to mapKITE use there, the mission finally could be executed in a successful way.

Now, as a 'special' type of drone mission, any company that wants to perform a mapKITE mission in Brazil has to ask for an accreditation and a mission security study has to be done to obtain it.

5.1.1.2. Performance analysis

https://youtu.be/GdngeGazKGg

The video shows a simulation of a mapKITE mission for a road corridor cartography mission near Assis, Brazil. The coordinates of the TV have been selected according to a real mission of interest by Engemap.

The mission starts in a small auxiliary path, parallel to the main road, to perform take-off and initiate the tracing. After that, 7 kilometers are operated with the tandem, up to a roundabout at the entrance of Assis, to finally exit on the first right exit towards the landing spot. The total mission time is of about 24 minutes long.

The drone and camera used in this simulation are not conveniently tuned to the mission needs. This is why the accumulation of lag (that is, distance between TV and UA) is excessive at maximum speed of 12 m/s. Just as a comparison, similar real missions in Brazil by Engemap (similar speed) have led to maximum distances of 50 meters, as compared to the 120 meters in simulations.

5.1.2. French coast monitoring

On the other hand we have the French coast monitoring, developed in March 2018 jointly with GEOSAT, a French big geomatics company that is specialised in the generation of 3D/4D maps about the terrain, buildings and other land infrastructures [12].

This project was named HYCOS as an acronym of Hybrid Coastal Surveying and its goal is to establish a service for monitoring accurately and frequently the evolution of the coastline based on a cross-sectorial approach: the combination of free satellite imagery data with the topographic LiDAR surveys with MMS and drone-based aerial photogrammetry. The proposed multi-resolution imaging approach will produce accurate 3D geo-spatial data of the monitored coast at a high resolution, high density and with a large coverage. This product will be used to analyze the phenomenon related to seasonal changes of the shore in sensible areas [13].

5.1.2.1. Applicable regulations' study

In regards to the French coast monitoring, the mission has been performed in a more evolved legal framework compared to the Brazilian case. France decided in 2014 to launch a really advanced drone legal framework by establishing height and horizontal distance limitations and operational prohibitions as it is explained in paragraph 3.1.3. The key point of why France is almost the only European country that has not changed its drone legal framework in the last two years is the fact that since 2014 it is established in the regulation that special drone operations should be exhaustively supervised by the French authorities, and that the mission security requirements and the specific operational limitations that the mission will have, must be agreed upon the French government.

So, as a summary, France in 2014, instead of banning all drone operations while a drone legal framework was being developed (what was done by almost all the other European countries) had the idea to analyse the drone market prediction and plan an accurate framework for its inclusion.

The HYCOS project with a mapKITE mission planned only had to ask the government for permission and agree to the conditions, and in few weeks the project was planned and executed successfully.

5.1.2.2. Performance analysis

https://youtu.be/EwaMyUbhtXc

The video shows a simulation of a mapKITE mission for a partial urban road and a partial coast/beach cartography. Actually, the interesting part is the beach, as it is the real aim of the mission. The coordinates of the TV have been selected according to the real mission performed in the frame of HYCOS project.

The mission starts in a road dead end, connected with the promenade to perform safely the take-off and begin the advance of the tandem. After the non-interesting mission part through the town, mapKITE reaches a roundabout with a coastal connection way. The first part of the beach cartography is done through the middle of the sand extension, and then the TV seems to go into the water for two times before finishing the mission. This can seem like an error but it is not. Precisely as the name of the mission says (coast monitoring) the map that Mission Planner uses and the actual sand state when the mission was taking place do not match, and so this is exactly the reason for non-adapting the TV waypoints file. The total mission time is of about 45 minutes in duration.

This time, the accumulation of lag is less than in the Brazilian mission because the largest straight part of the path is much lower than the one in Brazil so, there is not enough time to accumulate lag but the problem of tuning persists. The maximum TV-UA distance this time was over 55 meters and in the real mission this distance was much lower.

5.2. Simulation-as-a-product

These simulations will not only be a useful tool for the client, but also for GeoNumerics to present how mapKITE works, how the final product obtained is and which is specifically this final product. So, it would be a really useful marketing tool.

5.2.1. Product composition

The ‘product’ is composed by a fast-camera screen-film of the simulation inside Mission Planner’s platform, and some interesting written comments about the mission.

By this way any mapKITE target client could see a simulation of a real mission to get an idea of how this new application would work in his/her case.

5.2.2. Net distribution

The distribution of each video will have two components, the particular way and the global one.

As a quality assurance item, GeoNumerics will give the simulation of each mapKITE mission to the client during the mission planning, or at the end of the development. This video will be useful for the client to explain to anyone how the 3D orthomosaic (for example) that he/she is presenting was obtained. Moreover, if someone doubts the contraction of a mapKITE mission, GeoNumerics will be able to show a similar mapKITE mission and explain why its product is the best in the market with a nice graphical support.

As a pure marketing tool, GeoNumerics will upload a resumed version of each simulation to at least YouTube social network in order to get new clients through the promotion of the video.

CHAPTER 6. CONCLUSIONS

6.1. Objectives' fulfilment

All the initial objectives have been almost perfectly fulfilled. Obviously with some variations in regards to the 'initial conditions' but at the end the two necessities of mapKITE are actually solved.

6.1.1. mapKITE legal introduction

The regulations study of several countries about the actual paradigm and the future one has been developed successfully. After this study it should be noted that almost no country has taken into account a 'follow-me' scene in drone operations and this is a difficulty for the mapKITE application, but on the other side almost all countries have a risk-based regulation and the way to operate under these conditions is by performing safety risk assessments or installing DA systems in the drone or other risk mitigation measures, and this is an advantage because mapKITE can be easily adapted to almost all safety measures.

Finally, the most important point is that the European regulation framework will dynamite in 2020 all the rest of European drone regulations and a very elaborated new UAV scheme will be applied. This drone 'working-method' will take into account the follow-me case and at the same time will be risk-based so there will be no more problems with mapKITE application in Europe.

6.1.2. mapKITE's simulation environment

The results on the simulation environment have gotten a little bit away from the initial planned objectives. At first, the idea was to program completely the GUI so a mapKITE user could manage the operation easily. However, during the thesis development we re-assessed the work needed for developing the GUI and found that it would not be optimal, partly due to the criticality of the task and partly due to the increased effectivity of focusing in the simulation execution. What has been answered in this project is the need to perform several simulations to design the final product, which will also serve as a product presentation for future clients.

These simulations have been performed successfully after training a little bit with non-real cases and now there is a Mission Planner version with a GUI available and also some real-case simulation videos in the net for a mapKITE client with the objective that he/she could see how a mapKITE mission is before contracting the product and also a specific platform for it.

6.2. Future work lines

In order to continue developing mapKITE it would be interesting to propose some future working ideas so GeoNumerics will have a stronger product to face competing brands and reach a bigger portion of the market.

6.2.1. mapKITE legal introduction

The idea to continue developing the mapKITE specific regulations study is to add each mapKITE experience into the final regulations document. As mapKITE can be applied to an infinity of different scenarios, it makes no sense to pretend to think in each one and describing which would be the way to operate in each case. Apart from that, although the 2020’s regulation seems that it will be a definitive one, regulations in general are continuously evolving and changing so a closed regulations document is fated to become outdated.

Another idea to keep mapKITE into regulations framework at all times is to establish a good relationship with U-Space management (see Annex I) and inform them about any European operations planned, so they can elaborate a safety assessment study for each case in prevision to it.

6.2.2. mapKITE’s simulation environment

The first idea about the GCS is to publish it as a Mission Planner update in GitHub, as recommended by the platform creators to be done. This is so because of the nature of any open-source software that any specific update could be positive for any other user. In this manner it is not going to be necessary to download and install the specific version of GeoNumerics, but only to update the generic version of Mission Planner if it has not already been done in the client’s PC.

Another idea is to collect the client’s opinion about the GUI to introduce some further improvements, those which could help future mapKITE clients during the planning or during the mission.

Finally, exploring different follow-me-enabled GCS would be also valuable.

6.3. Environmental study

The environmental study of this thesis can be seen from two different points of view:

- Focusing on the development of the thesis, the environmental impact is minimum as neither the regulations study nor the development of the GCS and the simulations have needed any field practice to be done.

  The regulations study has been performed by reading many official communicates from different countries about their drone legislation rules, and since they are all available in the internet, none of thm has been printed.
  The improvement of Mission Planner and the simulations have been done by following several net-published manuals, and for the same reason, the environmental impact that they had has been null.

- Focusing on mapKITE as a product, yes, it has some environmental impact. Compared to how terrain mapping have been done until now, the use of an UA platform for the aerial photogrammetry instead of manned aviation is a huge reduction of emissions as the used drones for mapKITE should be all electrical powered.

  On the other side it is true that is difficult nowadays for the TV to be electrically powered. In both reported real cases they were gasoline-engine powered and is, so, the worse election for a TV in terms of pollution. The idea would be to try and choose a hybrid TV whenever possible as the number of these types of vehicles commercialised nowadays is reasonable enough as to use them without being at a high economic cost. In a near future, when electrical TVs result in the same percentage of vehicles as hybrid ones do now, that will become the optimal election and the environmental impact will again be greatly reduced.

  As a summary, the environmental impact of mapKITE, compared to the methods used years ago is really low, but is medium-high compared to the terrain mapping done using only drones, as the TV's environmental impact must be taken into account.

CHAPTER 7. BIBLIOGRAPHY

[1] mapKITE website http://mapkite.com/

[2] Spanish drone law 'Boletín Oficial del Estado #316 of Friday 29th December 2017' https://www.boe.es/boe/dias/2017/12/29/pdfs/BOE-S-2017-316.pdf

[3] French drone law https://www.ecologique-solidaire.gouv.fr/quelle-place-drones-dans-ciel-francais

[4] Brazilian drone law https://www.export.gov/article?id=Brazilian-Regulations-for-Drone-Operation & https://www.uavsystemsinternational.com/drone-laws-by-country/brazil-drone-laws/

[5] English drone law http://www.caa.co.uk/Commercial-industry/Aircraft/Unmanned-aircraft/Small-drones/Regulations-relating-to-the-commercial-use-of-small-drones/ & http://www.trustedreviews.com/news/uk-drone-laws-2018-3146402

[6] American drone law https://www.faa.gov/uas/ & https://www.newegg.com/insider/faa-drone-regulations-you-must-know/?nm_mc=KNC-GoogleKWLess&cm_mmc=KNC-GoogleKWLess-_-DSA-_-AllPages-_-NA&gclid=Cj0KCQjw6J7YBRC4ARIsAJMXXseFoBqbBFrlFCp_MaOziBZHqM8Xct9k0NudKAaQLO7d4NFyOtqdO_kaAtQzEALw_wcB&gclsrc=aw.ds

[7] European future drone law https://www.easa.europa.eu/easa-and-you/civil-drones-rpas

[8] Follow-me mode on QGroundControl https://docs.px4.io/en/flight_modes/follow_me.html

[9] Follow-me mode on Tower https://vimeo.com/104361616

[10] MAVlink protocol explanation https://en.wikipedia.org/wiki/MAVLink

[11] ENGEMAP company exposition *Intern GeoNumerics-ENGEMAP project presentation*

[12] GEOSAT company exposition https://www.geo-sat.com/fr/presentation-generale

[13] HYCOS project explanation
http://www.geonumerics.es/index.php/news/70-kick-off-of-the-hycos-project-co-coordinated-by-geonumerics-an-application-of-mapkite-to-coastal-monitoring

[14] Filippo Tomasello BIO https://rpas-civops.com/speaker/filippo-tomasello/

ANNEX I. CORUS WORKSHOP

AI.1. STRUCTURE SUMMARY

My attendance at the workshop was in the 23rd and 24th of January 2018. The aim of it was to well-define the limits and implications of the near-future U-space. Its intentions were to solve some questions as well.

The structure of the workshop was divided in eleven different sites inside the EETAC – UPC University, one of the schools of UPC (Polytechnic University of Catalonia). The first place was the event's Hall, where the introduction with the rules and the path for each group and the summary at the end of the day took place. The second one was the meeting Hall equipped with food & drinks and the accreditation team. The other nine rooms had a different stand in each and the objective was to work on a different topic in every stand. Each one had a Eurocontrol-related person as the leader.

The nine topics were:

1. Airport operations
2. High-risk operations
3. Medium-risk operations
4. VLL (Very Low-Level) operations
5. Low-risk operations
6. Legal elements
7. Architecture & Solutions introduction
8. CanOps basic questions
9. Societal impact

Each stand-leader planned a ten-minutes introduction plus a twenty-minutes activity in order to first explain which were the moment definition for each case and to pose one or some use-cases for then obtaining as much feed-back / opinion as possible using questionnaires or debates.

The summary at the end of each day was the method to present a preliminary results of each stand. The task of the leaders now was to present the most numerous answers for each posed question.

I think it was a great idea for constructing / defining a new paradigm (whose always have effect over a lot of people) having into account every opinion of the experts in the field in order to obtain the most satisfactory "product" at the end.

AI.2. CONTENT SUMMARY

AI.2.1. INTRODUCTION

The U-space definition: an ecosystem to accommodate all the drone operations and all which goes related with. Is depicted qualitatively in Figure AI.1.

Fig. AI.1 U-space qualitative information-exchange scheme

Its planned evolution trajectory is represented in figure AI.2:

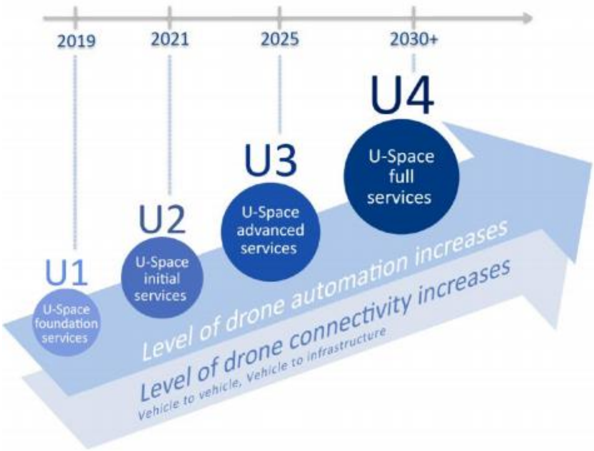

Fig. AI.2 U-space planned evolution through years

In order to evaluate the evolution, three more workshops are planned (each one with different objectives) until the U1 phase ends:

- 1st Workshop → January 2018 (Objective: Explore)
- 2nd Workshop → June 2018 (Objective: Define; CanOps V1)
- 3rd Workshop → January 2019 (Objective: Validate; CanOps V2)
- 4th Workshop → August 2019 (Objective: Disseminate; CanOps V3)

The way to explore all around the U-space in this first workshop was analysing the state-of-the-art of that already done. To do this, the method was to:

- Pose use cases.
- Debate about the desired services.
- Analyse the current constraints & propose a modification if necessary.

AI.2.2. AIRPORT OPERATIONS

The activity was divided in two parts:

- The first focused in twenty different possible activities to be done by drones in an airport. Each person in the group had the task of selecting ten of them and to say which advantages were the reason of the selection or which disadvantages of the other activities were the reason for not selecting them. Some airport operations planned were: Runway inspection, Bird monitoring or Airport cartography, all of them using drones.
- The second posed a use case: ILS inspection & calibration. A few questions like *'Which terrestrial or aerial danger can cause that operation?'* were planned. Each group member had to write in a post-it each answer that he or she thought.

AI.2.3. HIGH-RISK OPERATIONS

The introduction of this stand was about the definition and the distinction between the different categories:

- Open → Low-risk operations A in JARUS categorization
- Specific → Increased-risk operations B in JARUS categorization
- Certified → High-risk operations C in JARUS categorization

JARUS goes a bit more in deep about categories:

- A → Will not need quasi-anything
- B → All will depend on the operation, after the analysis of the operation some certifications will be needed
- C → All certifications will be necessary to begin with the operation. All excepting the operations certification, because of if all the other certifications are needed it has no sense. The operations certifications will be only needed in class B.

The activity planned a use-case: A BVLOS package delivery operation with a predefined route over a populated area. The questions for this case were like *'Which certifications or equipment will this drone need?'* or *'At which altitude* *would operate those drones and who would have to regulate the drone traffic?'* The answers were diverse but in the regulation authority was a consensus, the U-space organization should regulate the drone traffic.

AI.2.4. MEDIUM-RISK OPERATIONS

The introduction for this stand was a summary about the one before in the high-risk operations but defining more specifically the medium-risk cases.

The use case here was an agriculture long range mission in BVLOS using 2 drones combined with an eolic turbine inspection short range mission using 1 drone (each mission managed by a different operator). The first mission with a predefined route for the two drones and a manual one for the turbine inspection. Moreover, there was some people walking around.

The key point here was that specific or medium-risk operations needed to be too specific in terms of definition as it was said in the introduction of the specific category.

The debate began talking about the real risk of that operation, if it was more low-risk than medium-risk because the agriculture mission would not interfer in the other one (predefined paths for one and not many extension to cover for the other) and evolved to a different situation. The new situation planned an ultralight crossing at the same operation altitude of the drones and the conclusion was that now the operation was a high-risk one because at least in Spain, ultralights do not have any regulation or sense-and-avoid equipment so to keep the zone safe the drones would be who equip those sensors and systems because of their manoeuvrability so a 'medium-risk' operation could become a high-risk one in many cases.

AI.2.5. VLL (VERY LOW-LEVEL) OPERATIONS

In this stand the general question was: how to define those operations and its environment. Meaning how to manage them, which boundaries should their airspace have (2D limits and height), if they need to be controlled or not, if other drone traffic could be allowed in those airspace portions…

Generally the conclusions were that they cannot be uncontrolled operations, so some type of control would be defined, that the drones operating like this should have sense-and-avoid systems if they are operating near people and that this airspace should be well-defined but it should be managed because if a 'more important' operation has to cross it, the other 'less important' operations should be stopped or paralyzed during its cross.

Here the debate was more oriented about the property of those portions of airspace. Owned by the government in Spain and until reaching a specific height, owned by the owner of the parcel in Germany, for example.

AI.2.6. LOW-RISK OPERATIONS

Here the questions were the same for two different use cases:

- Use case #1: Forest photo taking with no other drones around and VLOS operation.
- Use case #2: Unpopulated area in artic ambient with no other drones around but a BVLOS operation.

The two defined as low-risk operations for the moment. The questions were:

- What can change the risk level of those situations?
- Do you think are really low-risk?
- Which is the potential of encounter many other drones either in those non-populated areas in a near future?
- It make sense to send a flight plan for low-risk operations?
- Which services should the U-space have to offer? Tracking the low-risk flights?

The conclusions were very similar with the VLL ones. Many situations can change the risk level (an ultralight or a helicopter coming), the question about thinking if they were actually low-risk operations evolved to: Actually low-risk operations exist? Because if many situations can change the risk level of the operation and that drone is not prepared enough, a catastrophe can happen.

Then, having into account the existence of low-risk operations, the question about the flight plan was not well answered, some said that nothing have to be notified, some other said that a notification would be enough and some others said that a little flight plan could be very useful.

The same happened in the tracking question, some thought that the tracking by U-space organization would be great and some others answered that that makes no sense because if the drone is tracked but it has not any collision avoidance system it will be useless.

AI.2.7. LEGAL ELEMENTS

The introduction of this stand showed the situation nowadays about drone regulation.

At a global level:

- ICAO – Chicago Convention 1944
  Paris Convention 1919
- ICAO – UASSG 2007 – RPAS Panel 2014
- ICAO – Circular 328 – UAS 2011
- ICAO – RPAS Manual (ICAO Doc. 10019) 2015

At a European level:

- EASA – BR 216/2008: EU Member States (UAS < 150 kg)
- EASA – A-NPA 2015-10 (Open, Specific, Certified)
- EASA – NPA 2017-05 (Introduction of the legal framework)

At a national level: (2 analysed sites)

- FAA: Need of a certification for each operation.
- AESA: Is known how it will be (what the government wants) but not how it will be (implemented).
  Special characteristic: A pilot operating BVLOS has to be certified as a radiophone manager.

After that, some questions were planned:

- What is CORUS?
- Which feelings about the current regulation?
- Which is the major problem of the current situation?
- What penalizes more your business?
- Priorities have to be considered in drone regulations?
- Which paradigm shift have more priority?
- Insurance questions (limits, core focusing, free responsibilities)
- What about integrating drones in VLL airspace (legally talking)?

The more important conclusion here was that priorities should be considered as the regular traffic, emergency operations should have priority over the other, the next cases were not well-defined.

AI.2.8. ARCHITECTURE & SOLUTIONS INTRODUCTION

The two general aspects in case were: operational architecting and system & service architecting.

In this stand my participation was really poor because it was of a high technical term level and it was no time to ask a lot, so the aim was to define the different sub-organizations or paradigms for the U-space.

AI.2.9. CANOPS BASIC QUESTIONS

This part was very focused in the possible definition of a drone flight plan. The planned questions were like:

- Which has to be the content in it? It should be differentiate the public and the private aspects?
- All drones must send a flight plan? Why?
- If after sending the flight plan an unsafe situation is created (i.e. not enough airspace capacity) can it be rejected? By who? How?

From this stand it was not a clear conclusion to extract. The people was divided between those who thought that a flight plan was desirable and those who thought that it would be useless. The same as at low-risk operations.

AI.2.10 SOCIETAL IMPACT

After an introduction of what surveys say about the thoughts of people about drones the questions made, in this case by the UPC teachers, were focused in the following topics:

- Benefits of drones.
- Privacy issues.
- Environmental issues.
- Double use of technologies.
- Transparency.

The clearest conclusion of this part was that drones should interfere people's life as less as possible and all potential problems relating drones and external people (not users) should be treated.

ANNEX II. mapKITE EXPERIENCE IN THE FRAME OF THE HYCOS PROJECT

AII.1. HYCOS EXPERIENCE AND DGAC AUTHORIZATION

During my thesis time, a big mapKITE milestone has been achieved: the first authorization by a civil aviation authority has been granted for mapKITE operations, paving the way for the adoption of mapKITE by professional users in the mapping community. The ‘Direction Générale de l’Aviation Civile’ (DGAC) granted a permission to execute mapKITE operations to Octocam, a Barcelone-based company partnering with GeoNumerics in mapKITE, given the compliance of their aerial platform and procedures with French categorization (scenario S1, category E).

This milestone was achieved in the frame of the HYCOS project, which is implementing mapKITE as a part of its multi-platform approach, combining the aerial drone platform of Octocam, equipped with a high-resolution optical camera, and the mobile mapping system of the French mapping company GEOSAT, equipped with LiDAR technology and optical cameras. The goal is to obtain high-accuracy 3D models of the dune beach at Cap Ferret in different periods of the year, especially after winter storm episodes, to measure the dune erosion in 4D.

On March, 22nd and 23rd, 2018 the consortium of the HYCOS project lead a successful mapKITE campaign (short video) and closely followed by stakeholders interested in Blue Growth. On-going efforts focus on post-processing for orientation and terrain reconstruction, and the next scheduled measurement campaign will take place in the same area in September 2018.

AII.2. HYCOS 3D POINT CLOUD

Next figure shows a comparison of the traditional mobile mapping product and the typical mapping mapKITE product. On the top image, we depict a 3D set of terrain points (point cloud), obtained with the LiDAR sensor of the terrestrial vehicle, and on the bottom one, the combination air-ground of point clouds (the aerial point cloud is extracted with photogrammetric techniques and colorized using the drone optical images). By this comparison, the improvement of mapKITE becomes apparent due to the extended coverage of the terrain. Note that the stand-alone ground vehicle is not able to map the top of the dune, and therefore not fully useful for erosion monitoring.

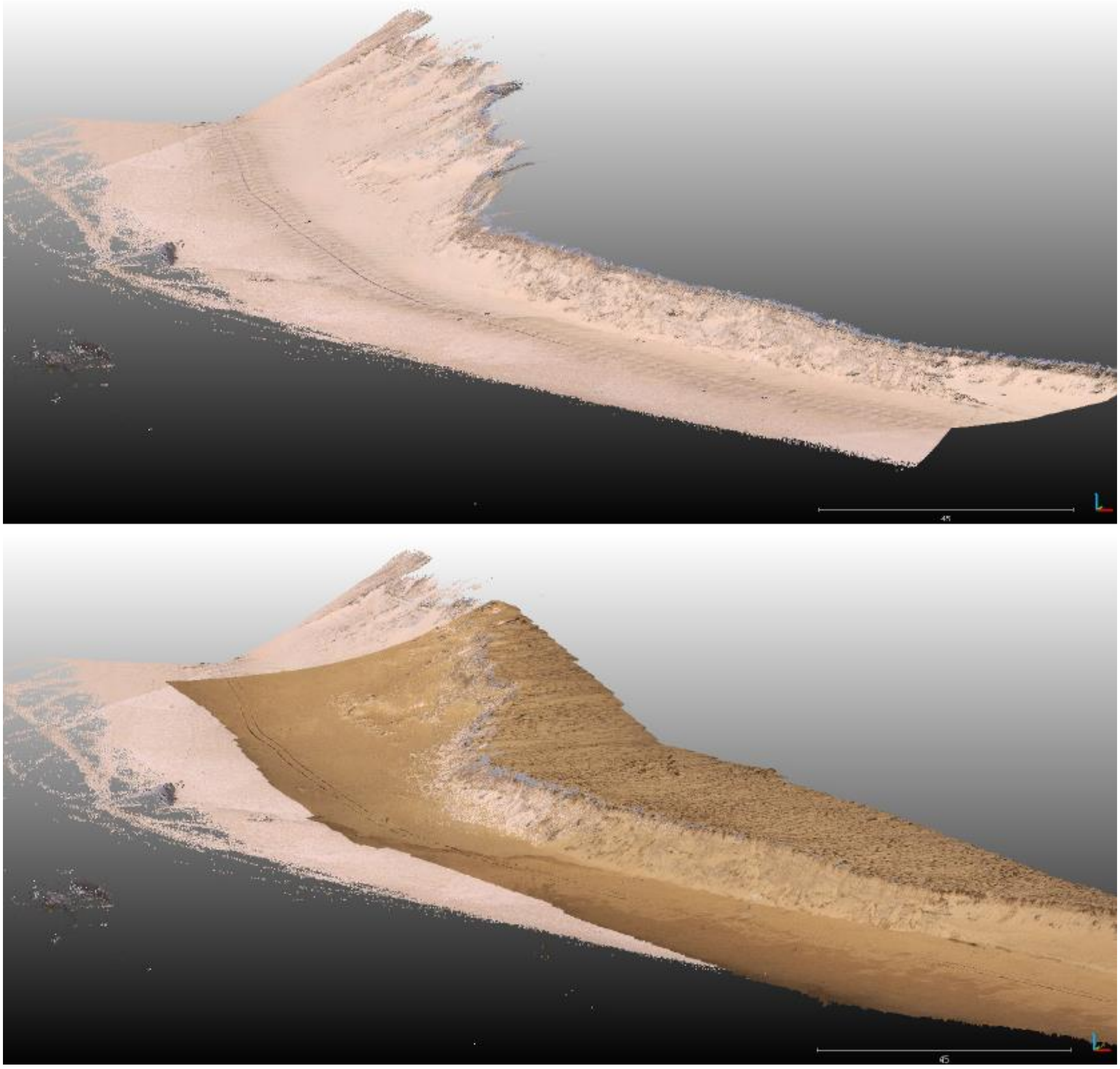

Fig. AII.1 Top, view of 3D point cloud obtained in Cap Ferret with MMS; Bottom, fusion of 3D point clouds from MMS and drone imagery

ANNEX III. QUESTIONS FOR FILIPPO TOMASELLO, EuroUSC ITALIA

Filippo Tomasello was a flight test engineer in Italian Air Force until 1984. Subsequently, he was responsible in ENAV (Italian civil Air Traffic Control) for R&D and modernization projects, for automation of Area Control Centres. He chaired the ICAO Aeronautical Mobile Communication Panel (AMC) which was in charge of electromagnetic-spectrum matters. Manager for coordination of ATM development plans in Northern Europe in EUROCONTROL since 2000. From 2005 worked at the European Commission on accident investigation, data collection and extension of EASA remit to ATM/ANS and aerodromes. In EASA from 2007 to Jan 2015, as rule-making officer, developed rules on ATM, aerodromes, flight operations, flight crew licensing and initial airworthiness, including related regulatory impact assessments. Since 2008 he was a focal point for rulemaking on Remotely Piloted Aircraft Systems (RPAS). He was the leader of a consultancy provided by EASA to the Europeans Space Agency (ESA) for regulatory compliance and safety of the project 'Iris' (aeronautical mobile communications via satellite over continental Europe). Member or chair of several ICAO Committees, Panels or Study Groups, including the UAS SG which developed the ICAO 'Manual' on the subject. Rapporteur of WG/2 (organisations) in JARUS. Earlier professor on international aviation safety regulation at 'Parthenope' University; now he teaches ATM and aviation safety at http://www.unifortunato.eu. Having left EASA in January 2015, became Technical Director of EuroUSC Italia, where now is the CEO. He also supports the Qatar participation to JARUS and, in ICAO, is a member of the Space 'Learning Group' and observer in the RPAS Panel [14].

We are elaborating a study about mapKITE, the tandem terrestrial-aerial mapping method patented by GeoNumerics. Due to its innovative spirit, mapKITE supposes a challenge for drone regulations all around the world. It is not usual to see a drone guided from a terrestrial vehicle in a 'follow-me' scheme, as well as a manual back-up pilot in motion on the same vehicle to keep the line-of-sight status.

For this reason, we would like to pose some questions related to the application of mapKITE to several scenarios both in current times and also once the European regulation will be totally in place.

1.- We know that almost in everywhere a corridor mapping in an interurban road, relatively away from towns or cities, can be done. Some countries will need to seal the road in order not to overfly any other car, or simply guarantee safe emergency landing conditions, but some others will not require it. Do you agree with this statement? Do you know any example/case of drone operations requiring or facing similar situations?

I do not agree totally with the statement. I would say that it does not only depend on the urban or rural environment, but on how much the road can be considered a 'sensitive' infrastructure: E.g. a motorway with 3 lanes in either direction and no speed limits is very different from a countryside unpaved but still public road.

In Italy these operations would most probably be considered 'critical' and hence subject to a safety risk assessment, demonstrating which safety mitigations may be appropriate (e.g. an observer looking in the direction opposite to car motion; flying not above but at certain lateral distance from the road, etc.).
In Italy there are several operators authorised for 'critical' operations, even if not exactly like the ones envisaged for mapKITE.
Italian rules are 'risk-based' and non-prescriptive. This philosophy was first applied in Europe through UK CAP 722 (1st edition 2002). Now it is the EASA position (Opinion 01/2018) and it is expected that the EU Member States will progressively converge, even before adoption of the common EU rules for the 'specific' category.

mapKITE application conclusion: These are good news for GeoNumerics because it means that at least in the EU now or in few years mapKITE could be operated everywhere obviously with different risk mitigations in each case but mapKITE's market seems to be very big.

2.- In Spain there is a specific regulation for drones piloted from moving cars and it specifies that the line of sight of the drone cannot be lost any time during the mission. mapKITE will put in place a backup manual pilot watching at the platform constantly, even if the drone lies a bit behind the vehicle, and in future, it would be fully FPV-operated. How do you see the mapKITE configuration as a continuous LoS scheme?

Indeed, it could be VLOS throughout the flight, assuming that the remote pilot on-board the car is able to turn her/himself in any necessary direction and maintain visual contact, which may require not to fly above a certain height depending on the conspicuity of the drone and the prevailing visibility conditions.
However, one observer (e.g. looking backwards or carried by a second vehicle) could extend the range to EVLOS.

The ‘follow-me’ mode is not yet fully developed, but regarding EASA Opinion 01/2018 one might infer that it would be sufficient for the remote pilot non necessary to see the drone, but the ability to monitor obstacles and other air traffic in the volume towards which the drone is going. Typical case could be a skier followed, behind her/him, by a drone. The skier would not see the drone behind, but she/he will be able to see the airspace ahead of the trajectory.

mapKITE application conclusion: These are again very good news for mapKITE because when European regulation will be totally in place (in 2020) will be enough to install a sense-and-avoid (SA) system in the drone as a horizontal risk mitigation measure to operate.

3.- Urban mapping supposes a more difficult challenge, at least from two perspectives. Firstly, usually overflying crowds is forbidden and secondly, there is a minimum vertical and horizontal separation from buildings established in any regulation.

- **Regarding the first, what is the vision about flying over crowds with drones? Will this limitation in practice ban all the ‘urban drone business’ such as package delivery, surveillance, etc.?**

  Indeed, foreseen EASA rules would prohibit flying over crowds in the ‘open’ category. If applying Specific Operations Risk Assessment (SORA) to the ‘specific’ category a drone with a maximum distance between propeller-tips not larger than 1 m could fly above crowds. In this case however, design mitigations might apply. A larger drone could still fly over crowds in the ‘certified’ category, but in this case an airworthiness certificate (e.g. TC by EASA) would be required.
  In conclusion it would be better not to fly over crowds (e.g. over a market square on Saturday morning), which does not exclude mapping the same area (e.g. very early on Sunday or Monday morning), when it will be ‘populated’ but not ‘crowded’.

- **Regarding the second, usually streets have buildings in the two sides and is not possible to maintain the horizontal minimum distance from buildings. What is the deal in this case? In case it is a hard limitation, does this mean that the urban mapping business with drones will be hardly developed?**

  In the specific category, depending on the accuracy and integrity of navigation, the safety risk assessment may demonstrate that closer distances are safely possible.

However, in this case, probably not only the normal operations need to be considered, but also the possible loss of control of the drone ('fly away'). Additional mitigations may be agreed with the local authorities (like prohibiting parking along a road during works of extraordinary cleaning); these may include information to population; invitation to close windows for few minutes; aural information through megaphones when drone is approaching, etc.).
In the specific category the basic tools are the 'safety risk assessment' and the 'OPS Manual' where all the procedures linked to mitigations are described in detail.

EU authorities will progressively follow the EASA 'risk-based' approach, which means that the operator, possibly supported by an independent Qualified Entity, should convince the Authority that the operations are sufficiently safe (i.e. risk assessment) and properly organized (i.e. mitigations implemented as described in the OPS Manual).
The postulate upstream of this approach is that drone operations can lead to thousands of different scenarios and hence over prescriptive rules are not appropriate.
This approach unfortunately requires a cultural change in the authority's inspectors, sometimes used to matrices of compliance, but not to safety judgement.

mapKITE application conclusion: Again the answer is referred on the future European regulation so it is convenient for mapKITE to be aware of all the specific details in time of complete application of it. As there is being a lot of time to develop this European drone framework, all possible safety mitigations should be taken into account when operating a drone so the key point will be the mapKITE Operations Manual in order not to have any problems with legal authorities anywhere.

4.- Railway mapping is another challenge for regulations because of the difficulty of stopping the train traffic during the time of the mission. In these case, regarding security measures to be taken into account, do you know which the procedure, if any, is?

Indeed, this is a challenge, but easy mitigations are possible (e.g. fly not directly above the rail line, but with a certain lateral offset; close the windows of the train; plan the drone operations in between passes if the line is not congested; etc.).

mapKITE application conclusion: Again, if railway authorities agree with these risk mitigation measures, good news for mapKITE as it seems that it would not be any problem at all to operate it in railways.

5.- How would the regulations interpret the possibility of using FPV in a mapKITE mission?

I cannot prejudge what the regulations would say. However, currently known positions are that a FPV camera is not a suitable device to ensure Detect and Avoid, although it may be accepted for specific activities (e.g. drone racing).
Personal opinion is that a camera looking almost horizontally (or at 1º below horizon) in the direction of the drone motion, could help the remote pilot to avoid obstacles on the ground before they become visible from the car.
Conversely, presently I see no benefit to use an FPV camera to monitor the airspace, which can normally be done from the car (except in presence of dense vegetation on the sides of the road, but in this case the operation would already become BVLOS).

mapKITE application conclusion: It seems that for the moment FPV mapKITE application should wait because it is true that an FPV camera cannot reach the sufficient resolution to detect obstacles in-time. Several FPV cameras differently orientated could be a solution as Filippo mentions but this will not be optimal so, as for the current drone traffic is not necessary, GeoNumerics will wait for a good-resolution real-time camera to implement mapKITE FPV.

6.- When applied, how would interact the European countries regulation (national level) with the European drone regulation framework? Who will have the power and in which part of the territory? Will the countries regulations lose completely their value?

European drone regulation will be mandatory for all Member States. Of course there will be a transition period for the CAAs before the entry into force at a National level.